# Urban Security

Los Alamos National Laboratory

1999 Annual Report

LAUR-99-5554

**“Mankind’s future will unfold largely in urban settings.”**

***Mega-City Growth and the Future*** **(edited by Fuchs et al., United Nations University Press, 1994)**

## INTRODUCTION

Urban systems are composed of a wide range of subsystems, including transportation, construction, energy distribution, communications, solid waste, food and water distribution, surface- and sub-surface water flow, the atmosphere, geologic setting, ecosystems, economic zones, and demographics, for example. These subsystems interact and produce the collective and often non-intuitive behavior of an urban system. This part of the framework demands high performance computing (HPC) since each subsystem alone can be an HPC-scale problem—tools now available at the DoE Laboratories.

To understand urban systems demands multidisciplinary approaches that account for physical processes, economic and social factors, and nonlinear feedback across a broad range of scales and disparate process phenomena. Research programs in the energy, defense, environmental, and computational arenas have developed many state-of-the-art models that can serve as components of an urban modeling system. These include programs in transportation, air quality, groundwater transport, energy distribution, network theory, communications, synthetic population modeling, natural hazards, and risk assessment.

The Los Alamos Urban Security Team includes environmental engineers, geologists, software designers, natural hazard specialists, mathematicians, hydrologists, civil engineers, atmospheric scientists, chemists, geographic information system specialists and transportation experts who work in collaboration with urban planners and environmental scientists from academia and the government. We are using high-performance computing platforms to adapt existing in-house process-oriented models and to develop new models that interact in an integrated system. The goal is a scientific competency in urban systems and an ability to simulate the dynamic and complex cities of today and the next millennium.

**Why Should The Los Alamos National Laboratory Study Urban Systems?** It is widely recognized that short- and long-term national security depends upon a judicious balance of investment in defense, economic, social, educational, and environmental programs. The vitality of our national infrastructure, which overlaps and merges with the aforementioned programs, is therefore critical to our national security. We believe that our nation is most vulnerable where the infrastructure elements converge—in the cities. Supporting this belief is the Presidential Decision Directive to the US Government to protect the Nation's critical infrastructure.

Our vision for the Los Alamos National Laboratory is to develop a cross-divisional applied research competency to model the vulnerability and response of urban systems to changes in physical environment, malicious attacks, social-political setting, and the economy.

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## URBAN SECURITY ACTIVITIES

To effectively develop the competency in urban security, we have divided the project into six areas: (1) urban air-water transport pathways, (2) earthquakes and urban infrastructure, (3) city recovery and growth, (4) airborne toxic release/traffic exposure[1], (5) linked atmospheric and hydrologic modeling, and (6) framework design. The long-term goal is to link these areas and others as a "system of systems." Some crossover between components is already occurring within the CD— for example, the team simulating city growth is working with the earthquake and infrastructure team to look at models of the growth of Los Angeles following an earthquake. The teams developing the architecture framework and the geographic information systems are working with the air-water transport team.

All of the teams are developing components that will provide research underpinnings of Laboratory thrusts including Chemical/Biological Non-Proliferation (CBNP) and Critical Infrastructure Protection (CIP)—there is a also symbiosis between Urban Security, DELPHI, CBNP,

[1] Part of the 1997 project. During FY98 this work was spun off into other projects.

TRANSIMS, SOPHIA, AND ELISIM projects, all of which are based on state-of-the-art capabilities in simulation science.

We are modeling these subsystems in detail using state-of-the-art models developed within the Laboratory. A challenging aspect of this research

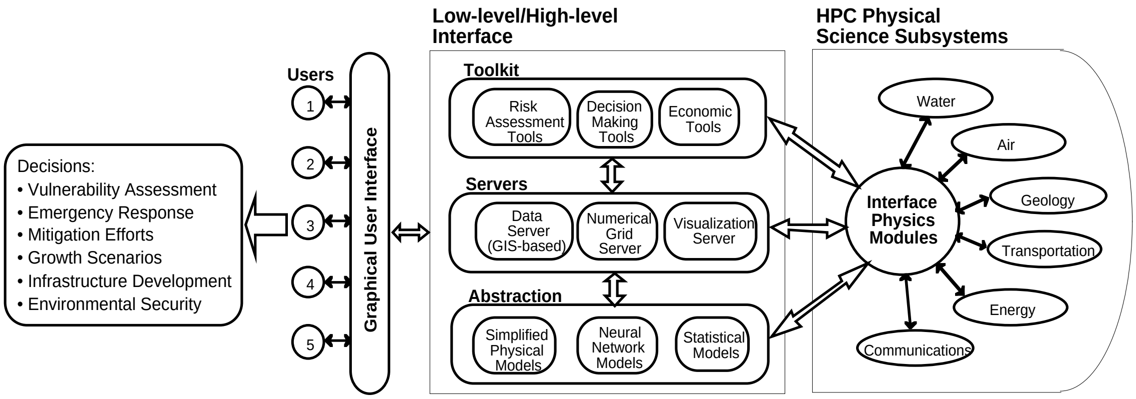


Figure 1. Schematic of proposed system architecture for answering urban security questions. Sophisticated numerical models from across disciplines and covering a broad range of scales will be integrated through interface physics modules. Methods for abstracting the “essential” physics will be utilized to speed computations and generalize results. Links between the physics-based models will be made to decision-making tools. Servers will provide data and visualization tools to the end-user.

effort is the understanding of the interfaces between the models (right hand side, Fig. 1). These subsystems are linked and their interaction produces the collective and often non-intuitive behavior of the urban system. This part of the framework demands high-performance computing (HPC) since each subsystem alone can be an HPC-scale problem.

We are linking models with a portfolio of research topics that force tailoring and interfacing the subsystem models. Our early efforts have focused on the high-level/low-level interface (middle, Fig. 1) and recently we have focused more on decision-making tools through our web-based consensus-building work. (left hand side, Fig. 1). Below we review our accomplishments in the six tasks described above.

## URBAN AIR-WATER POLLUTANT TRANSPORT PATHWAYS

We are simulating the transport of pollutants from source to sink in an urban environment. In order to follow the pollutants through the complete air and water pathway system, Many linkage difficulties had to be reconciled before we had an operational modeling framework. Our work has overcome different modeling domains, conflicting model purposes, and legacy code problems to produce the linked modeling framework described here.

Traditionally, air- and water-quality modeling has been performed separately. However, we now understand that most environmental problems require consideration of both the air and water systems and their interaction. The linked modeling framework we have developed can address a suite of environmental problems that previously could not be analyzed in detail. The air-water pollutant pathways modeling framework permits the user to derive information that can be applied to solve either new problems or old problems in new ways. To demonstrate the modeling framework we have selected a complex case study that will test our modeling limitations. Using the air-water pollutant pathways modeling framework, we have successfully simulated the transport and fate of nitrogen compounds through the air-water environment of the Ballona Creek subwatershed in the Santa Monica Bay watershed in Los Angeles, California.

In this work, we have focused on the transport and fate of nitrogen compounds because 1) they track through both the air and water pathways, 2) the physics, chemistry, and biology of the complete cycle is not well understood, 3) nitrogen compounds have important health, local ecosystem, and global climate implications, and 4) the problem required us to stretch our capabilities in non-traditional areas, including several relating to urban infrastructure and security. We have simulated the fate of nitrogen compounds in the Los Angeles basin from their source as nitrate precursors produced by auto and industrial emissions, tracking their dispersion and chemistry as they are transported by regional winds and eventually wet or dry deposit on the g round, tracing their path as they are entrained into surface water runoff during rain events and then carried into the receiving water system where dispersion and biologically-mediated chemical reactions take place (Fig. 2).

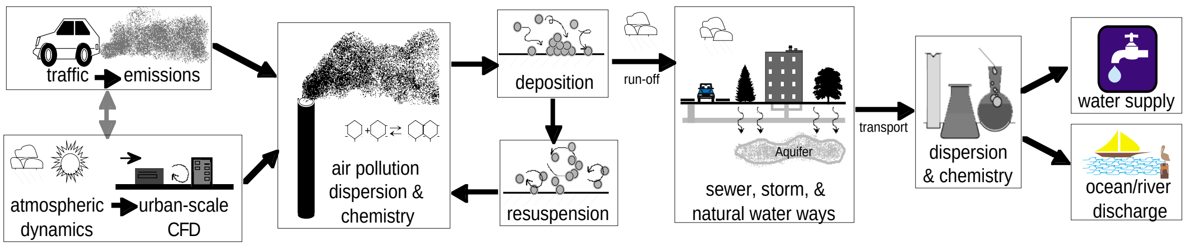


**Figure 2.** Nitrate pathway through the transportation, air, and water systems. The modeling system could be applied to many different kinds of air contaminants (e.g., from accidental spills, industrial sources, a CBW attack, pesticides).

**Model Descriptions** The system of linked models for studying the fate of pollutants through air and water pathways is shown in Fig. 3. In short, RAMS and HOTMAC provide time-dependent 3-d meteorological fields to the CIT air chemistry code for wet and dry season cases, respectively. CIT simulates the gas and aerosol phase chemistry and produces dry deposition fields of various pollutants. Wet deposition amounts are estimated from atmospheric concentrations of pollutants calculated by CIT at the start of the rainfall event. The deposited pollutants are input to the SWMM model along with precipitation fields from RAMS. SWMM computes urban runoff flow rates and pollutant concentrations, which are then utilized by the WASP model to simulate the fate of pollutants in a receiving water body. Our first year efforts concentrated on running each of the described models, obtaining data sets needed for model input and validation, and linking the models manually through I/O files in order to follow the pollutants through the complete system. Our work during the second year has concentrated on completing model development, creating links between the models, and testing the model linkage with a case study. Brief descriptions of the models follow:.

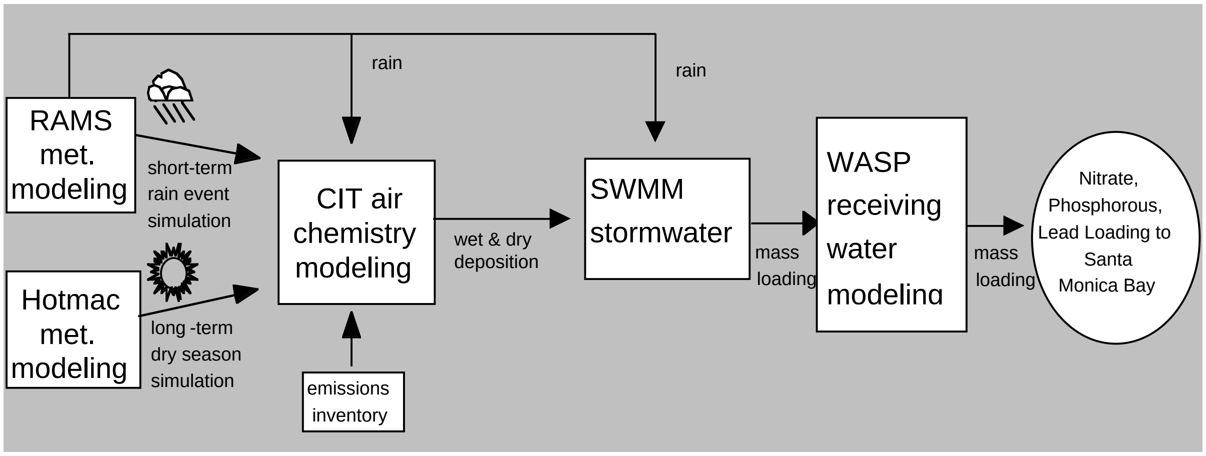


**Figure 3.** Modeling system for following pollutants through air-water pathways in an urban environment. With some modifications, the fate of pollutants from other sources could be modeled as well, for example accidental releases of toxic agents, heavy metals from brake pads, or noxious vapors from waste sites.

**RAMS** (**R**egional **A**tmospheric **M**odeling **S**ystem**)** and

**HOTMAC** **(H**igher-**O**rder **T**urbulence **M**odel for **A**tmospheric **C**irculation**).** RAMS (Pielke et al., 1992) and HOTMAC (Yamada and Kao, 1986) are both 3-d prognostic mesoscale meteorological models. Employing finite difference schemes, they solve the geophysical fluid dynamics conservation equations for mass, momentum, heat, and moisture, as well as thermal diffusion equations.

For wet weather simulations, RAMS is being run in non-hydrostatic mode and accounts for precipitation using a partial two-moment microphysics scheme, which includes eight water species. A nested grid approach using horizontal 80, 20, 5 and 1.25 km grid spacings is being used in order to cover the synoptic scale weather over the Pacific Ocean and Western US and to resolve the region of interest, the LA basin (see Costigan, 1998). For the dry weather simulations, HOTMAC will be run in hydrostatic mode and use an urban canopy parameterization to account for the effect of sub-grid urban effects (see Brown and Williams, 1998). A 15, 5, and 1.67 km nested grid scheme is being used. The outer-most grid covers the lower 1/3 of California, the intermediate grid matches the CIT air chemistry domain, and the inner-most grid is centered over the Santa Monica Bay watershed (see Brown, 1998).

**IT** **(C**alifornia **I**nstitute of **T**echnology Air Chemistry Code. The CIT airshed (chemistry-transport) model (McRae et al., 1982 and Russell et al., 1988) is a 3-d Eulerian photochemical model that solves the atmospheric diffusion equation using numerical methods. It uses the LCC (Lurmann, Carter, and Coyner) lumped-molecule chemical mechanism and contains a resistance-based dry deposition module. The CIT model has not been formulated for wet deposition, so we are calculating the total deposition of the soluble nitrogen species based on vertically-integrated column mass up to the model top at the start time of the rainfall event. The CIT model has a single grid mesh with 5km resolution. The modeling domain covers 1,725 $km^2$ of the Los Angeles basin from the high desert in the east to the ocean in the west.

**SWMM** **(S**torm **W**ater **M**anagement **M**odel**).** SWMM (Huber and Dickinson, 1988) is a large, comprehensive software package capable of simulating the transport of precipitation and pollutants from the ground surface, through pipe/channel networks and storage/treatment facilities, and finally to receiving waters. It is freely available from the USEPA.

Operationally SWMM is divided into computational and service "blocks”. This study has used the RUNOFF Block to simulate the transport of stormwater runoff and pollutants over the pervious and impervious surfaces of the urban watershed. The RUNOFF Block uses a non-linear reservoir model for calculating runoff and empirically-derived build-up/wash-off curves to estimate pollutant loading. Once the stormwater reaches a specified storm drainage inlet the TRANSPORT Block of SWMM was used to continue the simulation of the transport of runoff and pollutants through the storm drainage network. TRANSPORT uses the kinematic wave approximation (truncated St. Venant equations) for computing flow through pipes.

In this initial study, SWMM operated on the output from an atmospheric chemistry model (CIT) and rainfall records to drive the urban runoff simulation for several rainfall events. Shortly, we will incorporate rain produced at higher spatial resolution by the RAMS model and test the impact of spatial rainfall resolution on SWMM-produced runoff rates. The output from SWMM will be in the form of runoff hydrographs and pollutographs describing the time-variable response of the urban area to the precipitation and deposition loading and will then be used as input to the receiving water quality modeling component.

**WASP** **(W**ater Quality **A**nalysis **S**imulation **P**rogram**)** WASP5 (Ambrose et al. 1993) is a receiving water body contaminant fate and transport model. It is a dynamic compartment model utilizing equations based on the conservation of mass to determine the concentrations of chemical constituents from point of input to point of output. It can be applied in one, two, or three dimensions and treats a water body as a series of computational elements. Elements can be surface water, benthic porewater, surface of the benthos, or subsurface of the benthos. Environmental properties and chemical concentrations are considered spatially constant within segments.

The WASP program includes six transport mechanisms: advection and dispersion in the water column, advection and dispersion in the porewater, settling, re-suspension, and sedimentation of solids, and evaporation or precipitation. WASP is often connected to DYNHYD, a hydrodynamics program, which simulates the movement of water. In DYNHYD, the temporal and spatial movements of water are followed using a series of mass balance equations. WASP has two supporting sub-models: TOXI5 and EUT RO5. These models predict dissolved and sorbed chemical concentrations in the sediment and water column and predict the effects of nutrients and organic matter on dissolved oxygen and phytoplankton dynamics. EUTRO simulates the transport and transformation reactions of up to eight state variables within four interacting systems: phytoplankton kinetics, the phosphorus cycle, the nitrogen cycle and the dissolved oxygen balance. EUTRO solves a mass balance equation adding specific transformation processes for the eight state variables in the water column and benthos. WASP inputs include advective and dispersive transport, boundary concentrations, point and diffuse source waste loads, kinetic parameters, constants and time functions, and initial concentrations. WASP does not simulate overland flow which is the main mechanism of non-point source pollution, but can use the output from a nonpoint source model, such as SWMM, as input.

## ACCOMPLISHMENTS DURING 1998-1999

Our major accomplishments were in the areas of data collection, model linkages and model system demonstration. We describe each of these areas below:

**Data Collection.**

During the past two years, we have accumulated and processed large amounts of environmental and infrastructure data to develop the models. The data are being stored and managed in a GIS environment. Information needed for the models can be obtained from the GIS environment to suit their specific data needs. Most of the data collection has concentrated on the storm water and water quality models.

SWMM and WASP model development data were acquired from municipal and national government institutions. We constructed a GIS-based SWMM model for the Ballona Creek watershed using data collected from the Southern California Association of Governments (SCAG), the Los Angeles County Department of Public Works (LADPW), and USGS Digital Line Graph (DLG) and Digital Elevation Model (DEM) data. The

Ballona Creek watershed was divided into four catchments for modeling as shown in Figure 4: the Ballona Creek, the Sepulveda Channel, the Centinela Creek, and the Playa Vista catchments. SWMM had to be modified slightly to accommodate the immense size of the Ballona Creek catchment model.

We aggregated the 1993 SCAG land use data from 125 land use classes (the Modified Anderson Land Use Classification) into 10 land use classes for SWMM simulations. The 10 land use types are commercial, high-density residential, medium-density residential, low-density residential, industrial, institutional, open space, parks/public, transportation, and unknown/other urban. Storm drain data, e.g., size, length, slope, and conduit shape and type, were obtained from the microfiche vault at the LADPW and digitized into the GIS. DEM and DLG data were acquired to provide physical details of the watersheds, e.g., elevation and road locations. These data were used to define subcatchment and subcatchment parameters, e.g., width of overland flow, slope, dominant drainage pathways.

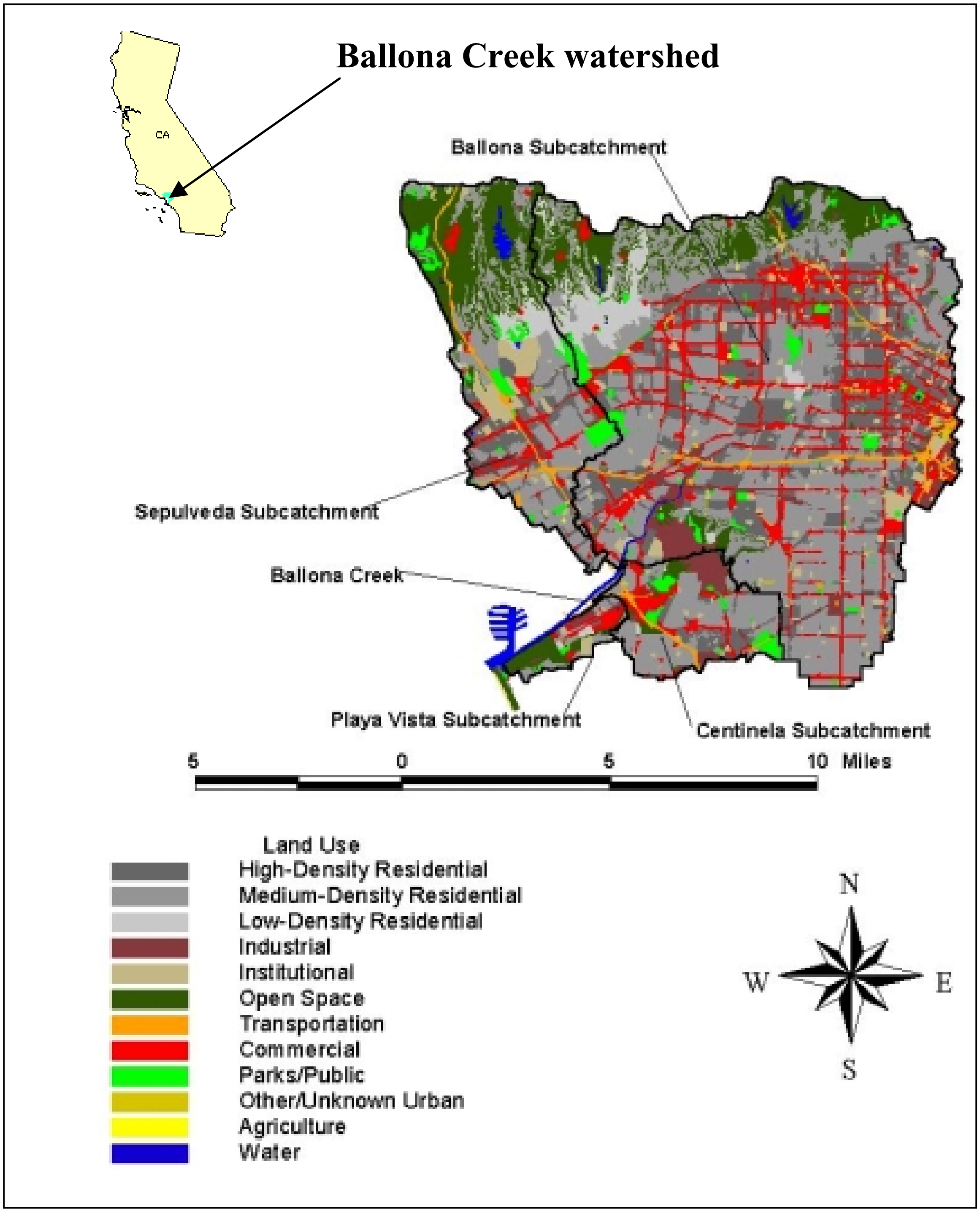


**Figure 4.** Ballona Creek drainage catchments.

To simulate runoff water quality from the four catchments we used a monitored event mean concentration (EMC) for each land use simulated in SWMM. An EMC represents the average pollutant concentration during a runoff event. We derived the average EMC over 17 storm events during two wet seasons monitored as part of the Los Angeles County Department of Public Works storm water monitoring program (LADPW, 1997, 1998). The average EMC was used in the SWMM modeling.

We completed work on the WASP receiving water quality model of Ballona Creek this year. The hydro-geometry of Ballona Creek was digitized into electronic form using information available from LADPW, the City of Los Angeles, and the US Army Corps of Engineers (Playa Vista EIR, 1994). The downstream model boundary was defined using tidal information obtained from the National Oceanic and Atmospheric Administration Center for Operational Oceanographic Products and Services (NOAA-COOPS). The upstream model boundaries were defined by a LADPW stream gauge during dry weather and from the results of SWMM wet-weather flow (WWF) simulations. These physical characteristics and boundary conditions defined the DYNHYD hydrodynamic model.

Since the data necessary for proper validation, calibration, and parameterization of the WASP code were not available we organized and conducted a water-quality monitoring campaign of Ballona Creek and the major contributing storm drains during dry weather. We contracted Dr. I.H. Suffet from UCLA to provide laboratory analyses of the water quality samples.

The water quality data were collected during dry weather conditions to avoid the inherent dangers of entering a storm drain that drains a 130 square mile watershed during wet weather conditions. Data were collected to define the loading of each chemical parameter affecting the cycling of nitrogen from each of the major catchments draining into the Ballona Creek Estuary. A time series of samples was collected at the downstream boundary of the Ballona Creek, the Sepulveda Channel, and the Centinela Creek catchments. Samples were analyzed for total Kjeldahl nitrogen, ammonia, nitrate plus nitrite, dissolved phosphorous, total phosphorous, chlorophyll-a, dissolved oxygen, and biochemical oxygen demand as well as other water quality parameters. Data were also collected on the flow and hydrogeometry at each sampling site. These analyses were also conducted at three sites within the WASP Ballona Creek Estuary water quality model to provide calibration data. Other data collected by the LADPW were used to parameterize the wet weather water-quality part of WASP. Additional reaction kinetic constants and dispersion coefficients for this study were selected from the most appropriate literature values, e.g., Bowie et al. (1985).

**Model Linkages**

We linked the five models in the air-water pollutant pathways modeling framework by developing procedures for transforming output from one model as input to another model. At this point in time, the linkage between the models is not automatic, however, the linkage between RAMS and SWMM, CIT and WASP, and SWMM and WASP is relatively straightforward. The calculated accumulated rainfall from RAMS can be inserted directly into the SWMM input file. CIT loads per unit area can be easily converted into loads per unit time for WASP input. And the flow rates and pollutant concentrations calculated by SWMM at specified discharge locations can be inserted into the WASP input file with some unit conversions. The difficult linkage was between CIT and SWMM, which are linked through dry and wet deposition. The CIT dry deposition fields are modified in a spreadsheet to account for processes that remove some of the deposited material from the catchment before it can be washed off during a rainfall event, e.g., nuisance flows, re-suspension and relocation, plant uptake, street sweeping. We do not yet have data to accurately represent the processes that remove nitrogen compounds from the land surface therefore we had to make "best guess" assumptions for the initial demonstration of the model linkages. The modified accumulated dry deposition fields are inserted into the SWMM input file as an initial load. The wet deposition estimates are based on assuming all of the CIT calculated atmospheric concentrations are washed out at the start of the rainfall event. The computed average concentrations of contaminant in the precipitation is then inserted directly into the SWMM input file.

**Modeling System Demonstration**

To demonstrate the application of the linked modeling framework, we selected a December 3, 1987 dry weather deposition episode and a December 4-5, 1987 wet weather episode that occurred during the 1987 Southern California Air Quality Study (SCAQS). Using wind fields derived from measurements, CIT simulated the dry deposition of several nitrogen species onto the Los Angeles basin. The initial load of pollutant on each SWMM sub-catchment was found by superimposing the CIT grid cells over the SWMM modeling domains. CIT estimated relatively high values for dry deposition of total nitrogen on December 3rd, but these values were expected because of the severity of the pollution event that occurred during the SCAQS episode on this date. Figure 5 shows the 24-hour dry deposition amounts of nitrate ($NO_3$) per CIT grid cell. The SWMM catchments overlay the CIT grid cells.

RAMS was used to simulate the atmospheric circulation and precipitation of the December 4-5, 1987 precipitation event. The RAMS simulations were initialized and nudged with gridded data derived form the National Centers for Environmental Prediction (NCEP) 2.5° gridded re-analysis. The simulations required the use of two-way interactive, nested grids. The largest grid is necessary to simulate the synoptic-scale flow features in the region. Grid 1 covers portions of the western United States and parts of Canada and Mexico. Approximately half of the domain is over the Pacific Ocean. Horizontal grid spacing on grid 1 is 80 km. Grid 2 includes the states of California and Nevada and has horizontal grid spacing of 20 km. Five-kilometer grid spacing is used on the third grid. Grid 3 is located over Southern California and includes the area where the CIT atmospheric chemistry model is employed. The fourth grid focuses on the Los Angeles metropolitan area with 1.25 km horizontal grid spacing. The fourth grid is large enough to include the Santa Monica and San Gabriel mountains. Precipitation calculated at this grid will be input to the SWMM models.

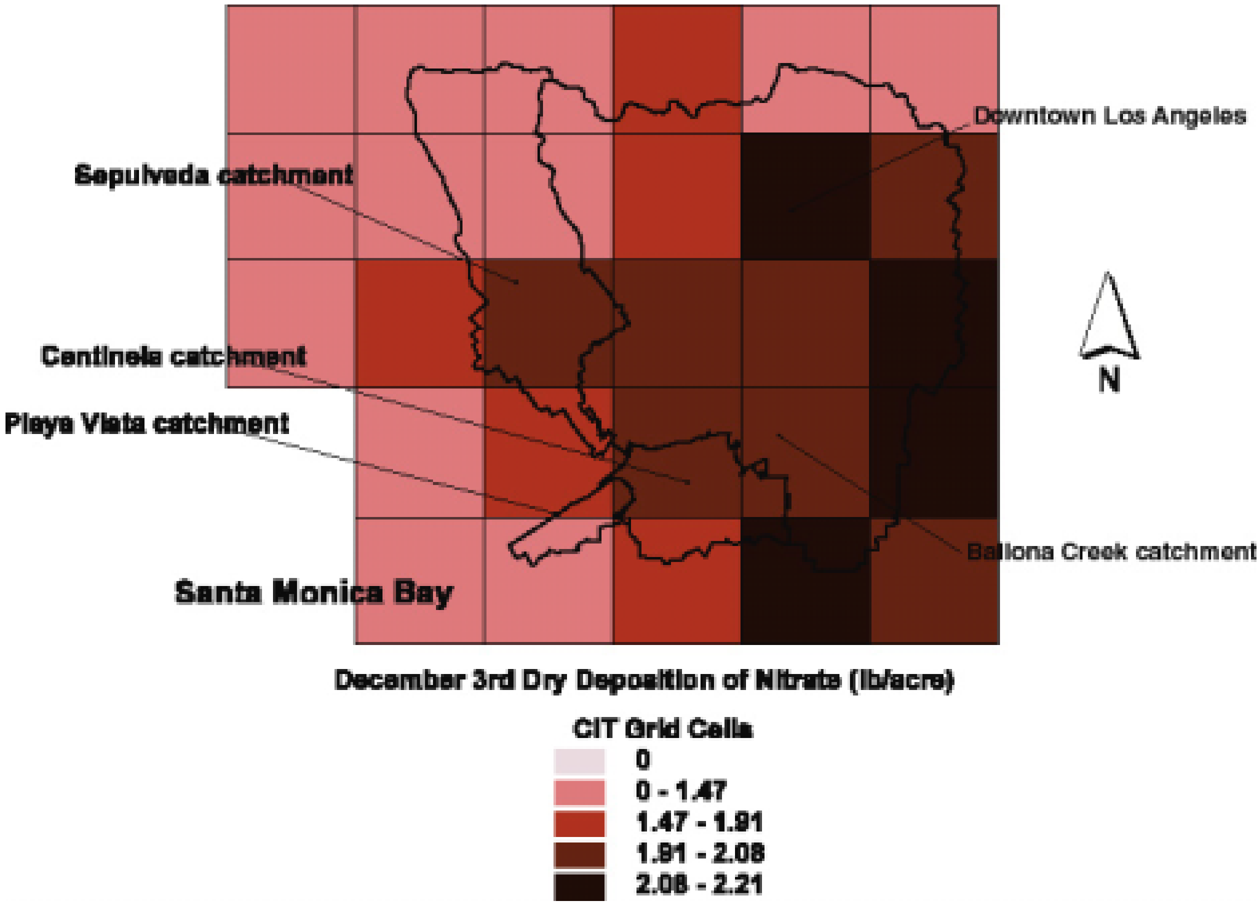


**Figure 5.** Total nitrate deposition (lb/acre) calculated by CIT for December 3, 1987.

Figure 6 shows the low-level wind vector field (overlain on the topography) for grid 4 at 5 PM, December 4th and the contours of accumulated precipitation on the surface at 5 PM, December 4th and 1 AM on December 5th. At 5 PM, December 4th, the wind field indicates an area of convergence where the southerly winds over the ocean meet off-shore winds. This is where the modeled precipitation was initiated. By 1 AM on December 5th, the accumulated precipitation covers a wider area. The observations of precipitation in the area were somewhat greater than the model predictions of the total precipitation. This may be due to inadequate resolution of the initial meteorological fields with the reanalysis data. We are currently adding rawinsonde observations to the initial fields and also plan to use observed sea surface temperatures (instead of climatological means) in hopes of improving the model predictions.

CIT calculated the concentrations in the atmosphere at the start of the December 4th rainfall event. These concentrations have been used to estimate the amount of nitrogen that is scavenged from the atmosphere during the rainfall event. The concentration of contaminant in the rainfall is calculated by dividing the mass scavenged during the rainfall event divided by the total rainfall volume falling on the catchment (Fig. 7).

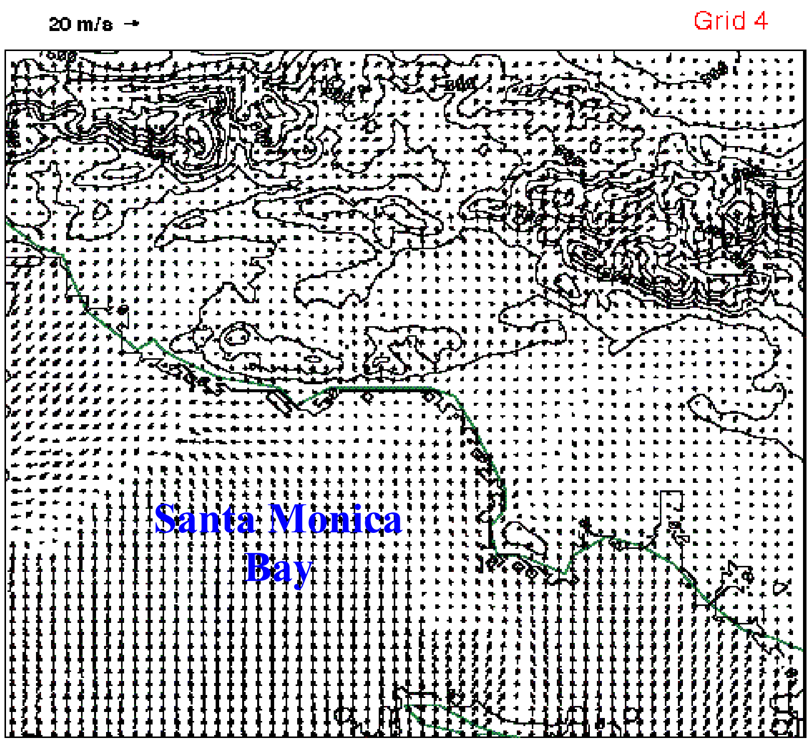


**Figure 6.** Low-level wind field plotted with the topography contours for grid 4 at 5 PMon December 4th.

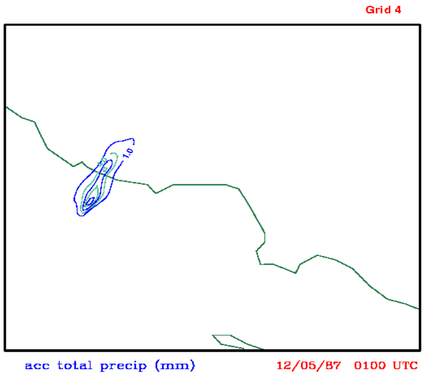


**Figure 7a.** Contours of accumulated precipitation on the surface at 5 PM on December 4th. Contours start at 1 mm and increment at 3-mm intervals.

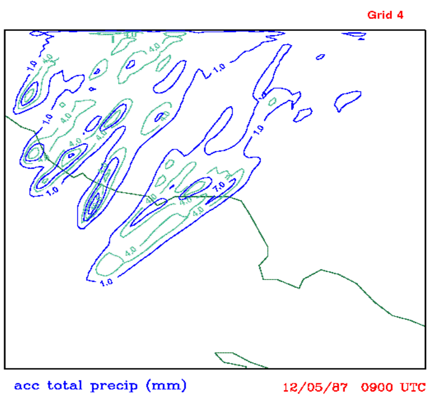


**Figure 7b.** Contours of accumulated precipitation on the surface at 1 AM on December 5th. Contours begin at 1mm and have 3-mm intervals.

The rainfall concentration is inserted directly into the SWMM input file to complete the linkage of CIT to SWMM. Currently, we perform the CIT-SWMM linkage manually, but in the future the linkage will be automated.

Currently, we have not completed the linkage of the RAMS simulation of the December 4th rainfall event to SWMM. In place of the RAMS data we used rainfall records from gauges within or near the catchments as input to SWMM. The recorded rainfall pattern drives the CIT-SWMM linkage. The results from SWMM include runoff hydrographs and pollutographs for the suite of nitrogen and phosphorus species important in water quality studies. SWMM calculated EMCs of nitrogen compounds in the stormwater runoff event on December 4th that were similar to EMCs estimated by the LADPW stormwater monitoring program. Although the simulated and measured stormwater runoff loads are similar, the CIT-SWMM linkage is not yet accounting for other sources of nitrogen in the watershed, e.g., residential fertilizer use. Hence, we may be overestimating deposition or underestimating the removal processes. We will address this in future research.

Figure 8 shows the nitrate concentrations in the storm drains of the Sepulveda Channel catchment three hours after the start of the December 4, 1987 storm event. From snapshots such as these, critical source areas can be identified. For example, the red colored storm drain showing a high concentration of nitrate drains a public park. Land use designated as public parks in our SWMM model contributes high levels of nutrients to runoff. At this point, we do not have field data to verify these results, although information such as this provided by the models could be used to guide data collection that would eventually lead to informed management decisions. Furthermore, a snapshot could be created for each pollutant at several points in time throughout the runoff event to display the runoff and pollutant concentration dynamics during the event. This would provide both spatial and temporal information that a water quality manager could use to identify critical source areas and the temporal significance of the critical source areas. For example, a certain area might be identified as a significant contributor of pollutant at the beginning of a runoff event, while another area might be shown to be more important later in the event. This information could direct the appropriation of funds to manage nonpoint source pollution on spatial and temporal scales.

In addition to data on the pollutant concentrations and flow rates within the Ballona Creek watershed, the SWMM model also calculates the discharge characteristics from the four catchments. These are then inserted into DYNHYD and WASP to simulate the response of Ballona Creek to the December 4th rainfall event. The Ballona Creek receiving water quality model provides time series of flow rates, depths, and contaminant concentrations in each of the modeled segments.

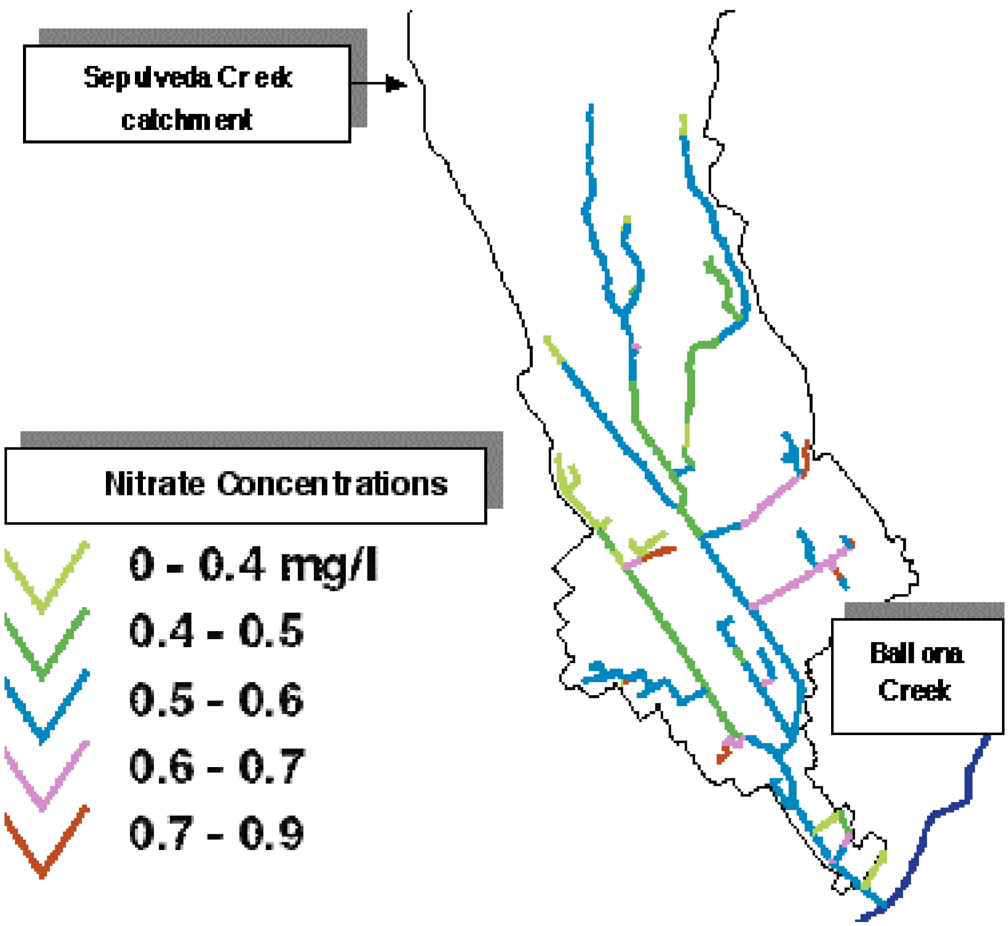


**Figure 8.** Nitrate concentrations in Sepulveda catchment storm drains three hours after the December 4, 1987 storm event begins.

## FUTURE WORK

The full linkage will be finished upon completing the RAMS meteorological simulation. Once the full linkage is operational, we can address a number of questions including (1) the contribution of air pollution to degraded water quality and how air quality management alternatives impact corresponding receiving water quality, (2) the impact of spatially variable rainfall on the performance of the storm drainage system, and many other important questions that can be solved only through linked environmental modeling. The full demonstration will be the subject of a future journal paper.

Besides the full model linkage, we have been isolating specific parts of the urban air-water transport pathways and studying their dynamics more closely to derive information to improve our understanding of the entire air-water system. We are in the process of using the large Ballona Creek water-quality database we have accumulated from various sources and the storm water modeling framework we have set up to study the Ballona Creek system during wet weather flow. With accurate estimates of dry and wet weather flow, we can identify which is most critical from a pollution control standpoint. Using these results, we can suggest if and when it is more appropriate to direct pollution management funds to dry-weather flow control as opposed to wet-weather flow control. An accurate estimate of the pollutant load in dry-weather flow can also be compared to the dry deposition load from CIT as can the relative effects of each of these loads. This topic will also be investigated as a potential journal article.

Another topic we are investigating that will result in a journal paper is the description and testing of the CIT-SWMM linkage. We also intend to investigate the RAMS-SWMM linkage closer and publish a paper on those findings.

## PRESENTATIONS DURING 1998-1999

Brown, M. J., September, 1999, American Nuclear Society Emergency preparation and Response Conference, Santa Fe, NM. Interdependent Models for Emergency Response Applications.

Brown, M. J., July 1999, *DTRA/GMU* Transport and Dispersion Modeling Workshop, Fairfax, VA - Urban Canopy Parameterizations for Mesoscale Met. Models talk

Brown, M.J., July 99, *USDOE CBNP* Annual Review, Washington, D.C.- Urban Canopy Parameterizations for Mesoscale Met. Models talk

Brown, M.J., April 99, *Arizona St. Univ. Environmental Applications* Speaker, Phoenix, AZ - Overview of Urban Air-Water Pollutant Pathways Work

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## EARTHQUAKES AND URBAN INFRASTRUCTURE

Our goal is to provide a set of science- and technology-based computational tools with real-time feedback for disaster planning, training, and management in time of crisis and long-term recovery.

Coupled analysis tools will dynamically simulate the operation of Los Angeles' linked infrastructures during and following an earthquake.
As a first step towards creation of this coupled system, we are simulating a major earthquake's effect on the electrical infrastructure within the Los Angeles basin. This set of tools has a computer-based, multi-layered Geographic Information System (GIS) database coupled to multiple models such as those for seismic ground response, infrastructure damage assessment, and simulations and analysis of infrastructures operations during emergency response and longer-term recovery.

The tool's multi-layered database will eventually include information on the geology of the area, ground motions for scenario events, a complete catalog of the infrastructure and its structural frailties (e.g., delineation of lifeline routes and nodes such as substations, interchanges; critical facilities such as hospitals, fire and police stations, utilities such as dams and power stations; communications; and selected building stock: classes of buildings and vulnerabilities according to construction type), all socio-economic systems, and regional demographics.

For a given scenario, the simulation system will calculate the propagation of seismic shock waves and the resultant ground motions. The low-frequency part is computed using a sophisticated 3-D model of the subsurface, and higher frequencies, less affected by the basin structure, is computed using a stochastic approach (Tumarkin and Archuleta, 1997).

The ground motion predictions are used to estimate damage to the infrastructure-probabilistically at first, but ultimately stochastic algorithms will select a specific set of damaged infrastructure components and create a specific damaged city environment. Dynamic simulations of the damaged linked infrastructures would then illustrate how the earthquake affects the city's ability to function. Within this damaged environment, emergency response scenarios will be simulated to rescue and treat injured people and to restore vital services. Various cleanup, restoration, and recovery alternatives would be explored to rapidly return the damaged city to near normal. Analyses of longer term rebuilding alternatives would identify those infrastructure investments that would lead to a more robust, sustainable urban system. Results of all these simulations will be displayed with high-quality graphics.

The unique nature of this project is two-fold; the ground response is based on non-linear seismic models and the models require ASCI computing capability at Los Alamos. This first product would be used by contingency planners as a pre-event planning tool; by responders as a real-time, event-specific information source and damage assessment tool; and by both planners and responders to model losses, to rapidly determine the needed resources, and to estimate social-economic impacts of both real and simulated events. All groups could use the tool to model and implement plans for urban damage mitigation, recovery and re-growth.

**Earthquake Modeling**

Realistic predictions of earthquake ground motions and of the damage that results from strong motions requires treatment of the important physical processes that influence the distribution of ground motion amplitudes within the urban setting. In addition to the magnitude, character, and location of the earthquake rupture, important effects include focusing of earthquake energy in sedimentary basins (Olsen et al. 1995), amplification of ground motions in low impedance soils (e.g. Murphy et al. 1971), and de-amplification caused by non-linear soil response (e.g. Joyner and Chen, 1975). In a study of ground motions recorded during the 1994 Northridge earthquake and its aftershocks, Field et al. (1997, 1998) determined that, while low-amplitude 1-Hz aftershock ground motions at soil sites were approximately three times stronger than motions at rock sites, motions produced at soil sites by the main shock were only 1.5 to 2 times stronger than at rock sites. Field et al. interpreted these results as pervasive non-linear response of the soils in the San Fernando Valley. If this interpretation is correct, neglect of the ef fects of non-linearity in simulations can result in a significant over-prediction of damage at soil sites.

However, O' Connel (1999) has suggested an alternative explanation for the difference between the weak and strong motion amplification ratios as elastic scattering by random-correlated crustal fluctuations. He was able to reproduce some of the weak-to-strong motion ratios in a completely elastic model. It is therefore imperative to find out the extent of non-linearity in the ground motion for the design of future ground motion estimation schemes.

In a collaboration between the Los Alamos Urban Security team and Dr. K.B. Olsen at University of California-Santa Barbara, simulations were performed of seismic wave propagation in one-dimensional soil columns using input ground motions at depth from Olsen's three-dimensional extended-fault simulations of the Northridge earthquake. Use of S-wave velocities, densities and laboratory strength measurements taken directly from the ROSRINE project (Schneider, 1999), produced linear-to-nonlinear ratios similar to Field's weak-to-strong motion ratios at the Newhall fire station (Figure 9). At the Jensen generator building, the linear-to-nonlinear ratios under-predict the ratios by Field, probably because of the well-known interference of building response. These results support the claim for pervasive non-linearity by Field. However, more sites must be included to extend the generality of the conclusions.

In addition, a generalization of the Masing Rule-used to calculated hysteretic stress-strain curves (Pyke,1979) was tested in the one-dimensional simulations and is now being implemented in two dimensions. We plan to continue this work, as well as investigating the

possibilities of including an approximate computation of non-linear effects into the 3-D finite-difference schemes.

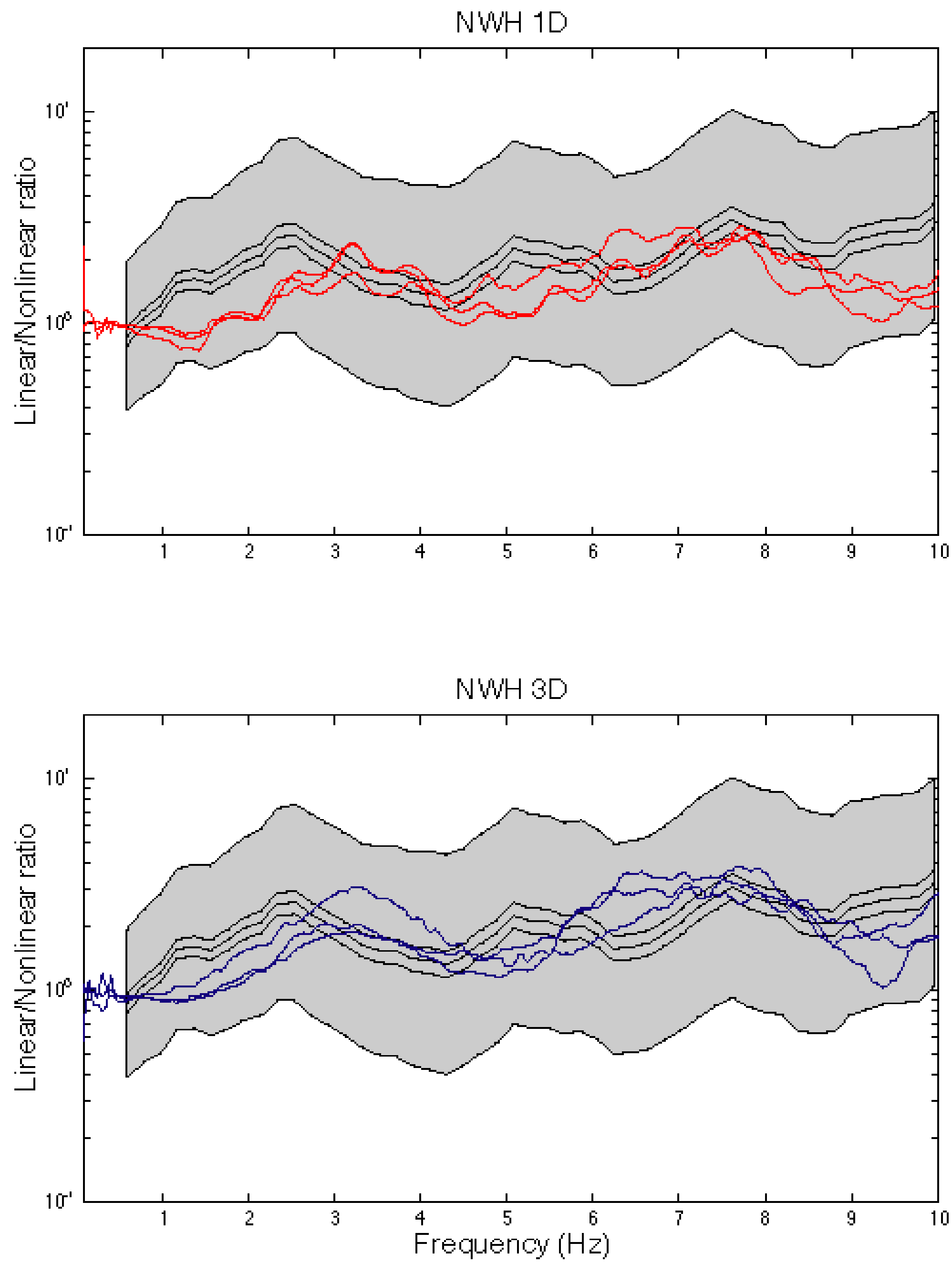


**Figure 9.** Comparison of simulated nonlinear effects to data at Newhall Fire Station. Fourier acceleration spectral linear-to-nonlinear ratios for three realizations using a (top) 1-D and (b) 3-D earth model for the source computation. The results are compared to weak/strong motion ratios by Field et al., 1997. Shaded region depicts area spanned by one standard deviation of data points. Dashed lines depicts mean +/- one standard deviation of mean. For both the 1-D and 3-D realizations of the ground motions, the linear-to-nonlinear ratios are similar to the weak-to-strong motion ratios, supporting the hypothesis that non-linear soil response was pervasive in the San Fernando Valley during the Northridge earthquake.

The electrical-power infrastructure (EPI) is particularly important to the urban organism as almost all modern-day urban activities rely on it for proper functioning. The need for electricity requires no major discussion. It is well known to everyone that electricity is important not only for lighting, heating, ventilation, air conditioning, operating various appliances, etc. but also for emergency communication, vehicular and air traffic control, and all control systems in command and control operations and also in commercial and industrial operations. Thus the loss of electricity during earthquakes can cost billions of dollars in lost production. The electrical network is also particularly vulnerable to earthquake damage as can be seen in the breakdown in power supply during earthquakes in Loma Prieta and Northridge, California. This summary is abstracted from Maheshwari and Dowell (1999).

Earthquake damage to the electrical network an is not restricted to the geographical location of the earthquake alone but has far-reaching regional implications. For example, the damage to electrical network components in Los Angeles after the Northridge Earthquake caused power outages as far away as British Columbia, Montana, Wyoming, Idaho, Oregon, and Washington (the longest one lasting 3 hours in Southern Idaho) (Schiff et al., 1995). This can be caused by either first-order direct damage to the generating stations, substations, or transmission and distribution networks; or to second-order indirect damage caused by the change in load related to consumer demand. Therefore, electrical networks need to be assessed in terms of their vulnerability to damage from natural hazards, not simply to the local network, but rather to the system as a whole. This is of utmost importance in understanding how, for example, an earthquake in Los Angeles will affect regions far beyond the Los Angeles metropolitan area. To understand the system performance of the electrical network after an earthquake, there are three important models that need to be integrated –

1) Generation of best-possible ground-motion parameters (peak ground acceleration, peak ground displacement, or response spectrum) for the scenario earthquake.
2) Combining ground motions with component fragility to compute the damage state for each of the power system's components. Using the

3) damage-state probabilities to undertake a systems-engineering analysis of the electrical system performance.
4) Using the damage-state probabilities to undertake a systems-engineering analysis to assess the performance of the electrical system during an earthquake and to use the results to retrofit facilities at risk.

Although each of the above models has been developed and used singularly, the need to integrate them is crucial to any kind of damage assessment. The integration also involves the exchange of input and output values in a way that the results of one model can be used by another. The objective of the Urban Security/ELISIMS research in this area is to understand this integrated approach to modeling and to demonstrate the results of a test of this approach in the context of a scenario earthquake of Richter scale magnitude 6.75 on the Elysian Park fault under downtown Los Angeles.

Coupling analyses of ground motions and consequential analyses of probabilistic failures of infrastructure components with the engineering analyses of the power flow through the EPI presents several novel challenges. One of the most interesting of these challenges is the identification of geographical areas served by the (radial) distribution systems emanating from EPI transmission substations. Individual substations serve a distribution network that provides electrical power to consumers in a specific geographic area (service area). Although this area is known precisely to the utility, it is not documented by public regulatory agencies. Ergo, the area must be estimated by non-utility organizations performing geographic-based (e.g., urban-planning) studies. This problem has been examined previously using Voronoi estimation techniques (Newton and Schirmer, 1997), but that approach has deficiencies in its ability to use population-density and land-use data to improve service-area estimates or to avoid water and rough-terrain obstacles that present service-area constraints. Los Alamos National Laboratory (LANL) has explored a cellular-automata service-area estimation technique for improved use of geographic data (Fenwick and Dowell, 1999) and with application to load-forecasting using synthetic-population methods (Dowell, 1999).

Another significant challenge is the coupling of the probabilistic failure states of substations computed by HAZUS™ (HAZUS™ is a program created for the Federal Emergency Management Administration to estimate loss during natural disasters) to a scenario of failures specific to discrete components represented in the EPI database. A direct method for a measurement of component failures is the Monte Carlo technique. Using a random number generator (L'Ecuyer, 1988), a failure state for each component is selected from the range of failure states using the HAZUS™ failure-state probabilities as a mathematical mapping function. Then the component failures are reported to the EPI database for subsequent evaluation of consequences to power flow through the components that survived the earthquake. This Monte Carlo procedure can be repeated to generate a probabilistic prediction of EPI transmission or voltage problems, or the similar likelihood of blackout for specific geographic locations.

A significant uncertainty in the assessment of post-earthquake consequences of EPI power-flow conditions is the range of human and machine events that will occur following a stress to the EPI. Specifically, the greater load loss relative to loss of generation capacity anticipated from an earthquake in the Los Angeles area will leave Western Systems Coordinating Council (WSCC) with a surplus of scheduled generation. To control voltages and to maintain a 60-Hz system frequency, automatic and manual choices will be made to turn off generation across the area administered by the WSCC. These choices involve decisions by human operators at utility and independent-system-operator control centers, and the range of choices makes prediction of the decisions difficult. Even the actions of the automatic generation control systems are difficult to predict, because of the proprietary nature of these control systems, the variations in policies for load shedding and voltage control among the several utilities of the WSCC, and the complex and temporally-dependent nature of these systems.

Another objective of the analyses of the implications of earthquakes to the EPI is the evaluation of policies for urban planning, infrastructure development, resource allocation, and infrastructure restoration. However, the output from the EPI engineering analyses is a prediction of the electrical state of the various EPI components. Coupling these engineering analyses with policy decisions is an important challenge. Although outwardly unrelated, EPI calculations can reveal information useful for selecting policies. Specifically, the identification of likely infrastructure failures is useful for determining the type and quantity of spare parts needed for infrastructure restoration. The expected quantity and cost of these spare parts, and decisions about desirable locations for their storage, can be determined from analyses of EPI damage from earthquakes. Likewise, such an analysis can assist in planning for emergency generators in essential facilities in areas that are likely to have blackouts. Furthermore, by running this analysis for many different scenarios, one can analyze the damage patterns, study which substations are likely to be damaged under many scenarios, and to prioritize the mitigation and restoration strategies for each of the substations.

The procedure for EPI analyses in this study is to couple the results of the HAZUS™ analyses to the EPI database, perform base-case and post-earthquake power-flow studies, and present the results in GIS and tabular formats.

A damage scenario is produced from the HAZUS™ results by selecting a damage state for each EPI substation using a Monte Carlo technique. The HAZUS™ results report the percentile probability that the damage state will be "no damage," "slight damage," "moderate damage," "extensive damage," or "complete damage." The probabilities for each state comprise a partition of the real-number space between 0 and 1. A random number (L'Ecuyer, 1988) between 0 and 1 selects a state for each substation from the possibilities, and this state is used for the subsequent EPI analyses. With "no damage," no modification is made to the substation in the EPI database. For "complete damage," the substation is removed from the database, and any connected generating units or transmission lines are disconnected and are removed from the database. Similarly, "extensive damage" (independent 70% probability of failure of each circuit breaker, switch gear, bus component, transformer, etc.), results in a likelihood of less than 0.07% that each transmission circuit terminating at the substation will remain operable. Substations having "extensive damage" were removed from the database, along with the incident generating units and transmission lines. For substations with "slight or moderate damage," the substation was left in service in the database, with a reduction in the aggregate consumer load resulting from probable failures of portions of the substation’s distribution apparatus.

The EPI analyses determine power flow through each transmission line and the voltage at each substation node. An analysis was performed for the base case (pre-earthquake condition under the assumptions of the California Independent Service Operators [CaISO] data set) and for post-earthquake conditions for a single Monte Carlo scenario sampled from the HAZUS™ analysis of an Elysian Park earthquake. Differences between the results of these two analyses indicate consequences of the earthquake.

GIS presentation of the results was made possible by geographic information obtained from maps from the California Energy Commission and the Federal Energy Regulatory Commission. These maps were scanned and registered for display by commercial GIS software, with overlays digitized from the maps to indicate the locations of EPI components found in the CaISO database. The digitized GIS objects allow a graphical presentation of the results of the EPI analyses.

The digitized substation locations were superimposed on a GIS database of Anderson land-use codes for geographic subregions throughout the Los Angeles study area. Our cellular-automata software, which estimates the service areas of each substation in the study area, processed this graphical presentation. The resulting bitmap image allowed additional graphical presentation of the consequences of the earthquake.

The HAZUS™ results found 43 substations with a probability of extreme or complete damage exceeding 50%. The Monte Carlo-selected scenario damage states for each substation in the Los Angeles study area showed a strong correlation between the substations experiencing complete failure with the location of the Elysian Park fault.

Figure 10 shows areas of Los Angeles where blackout occurs either from first-order isolation caused by the failure of a substation cutting off the flow of power to the distribution system, or from second-order isolation by substation failures removing all transmission paths to substations downstream. Blackout will occur at a substation experiencing second-order isolation because no transmission circuits remain to bring power to these substations, even though no earthquake damage occurred at the substation. Using data from the CaISO database for the 1999 summer-peak-load, the first- and second-order isolation removes 11,448 MW of consumers' loads and 4,400 MW of scheduled generation from the EPI. The load removed by the Elysian Park earthquake scenario is 8.9% of the entire WSCC EPI load. The removed scheduled generation is 3.3% of the entire WSCC EPI generation. These perturbations leave WSCC with a significant excess of scheduled generation. This excess generation will produce higher-than-nominal voltages and increased system frequency. Manual and automatic generation control must reduce the generation to match the post-earthquake load to prevent these voltage and frequency problems.

As an academic assumption, we reduced the surviving scheduled generation uniformly (to 95% of the scheduled value) across the WSCC.
This reduction in generation matched closely the post-earthquake demand (plus transmission losses resulting from the new generation schedule). The consequent power flow revealed surprisingly few problems for the WSCC EPI. Two types of problems occur. First, power flow is shifted by the line failures and changed load and generation schedules, producing thermal overloads (flows that exceed the thermal capacities of transmission lines). Overloads that occur are small (a few tens of megawatts on only eight transmission lines) and could be mitigated by changing the post-earthquake generation schedule. Second, the failures produce changes in reactive power flow that lead to non-nominal voltages at substations. These problems are more serious. There are 129 substations with voltages 10% or more above normal, and one substation with voltage 20% above normal. These are large excursions from the normal voltages, and could exceed the capability of the voltage-control apparatus to mitigate these

abnormal voltages. These abnormal voltages occurred throughout WSCC (Figure 11). Several of these substations' abnormal voltages are serious problems, particularly those at substations of the high-voltage backbone through northern California, Washington, and Oregon. Abnormal voltages occur at the Malin, Captain Jack, and Grizzly substations in Oregon; Hanford, Ashe, Lower Monumental, Little Goose, and Lower Granite substations in Washington; Round Mountain and Olinda substations in California; and at substations as far away as Colorado and British Colombia. More information is necessary to predict how the WSCC EPI's relays and other devices would respond to these abnormal voltages, to determine if there could be cascading failures that would result in blackouts of areas far removed from Los Angeles for this Elysian Park earthquake.

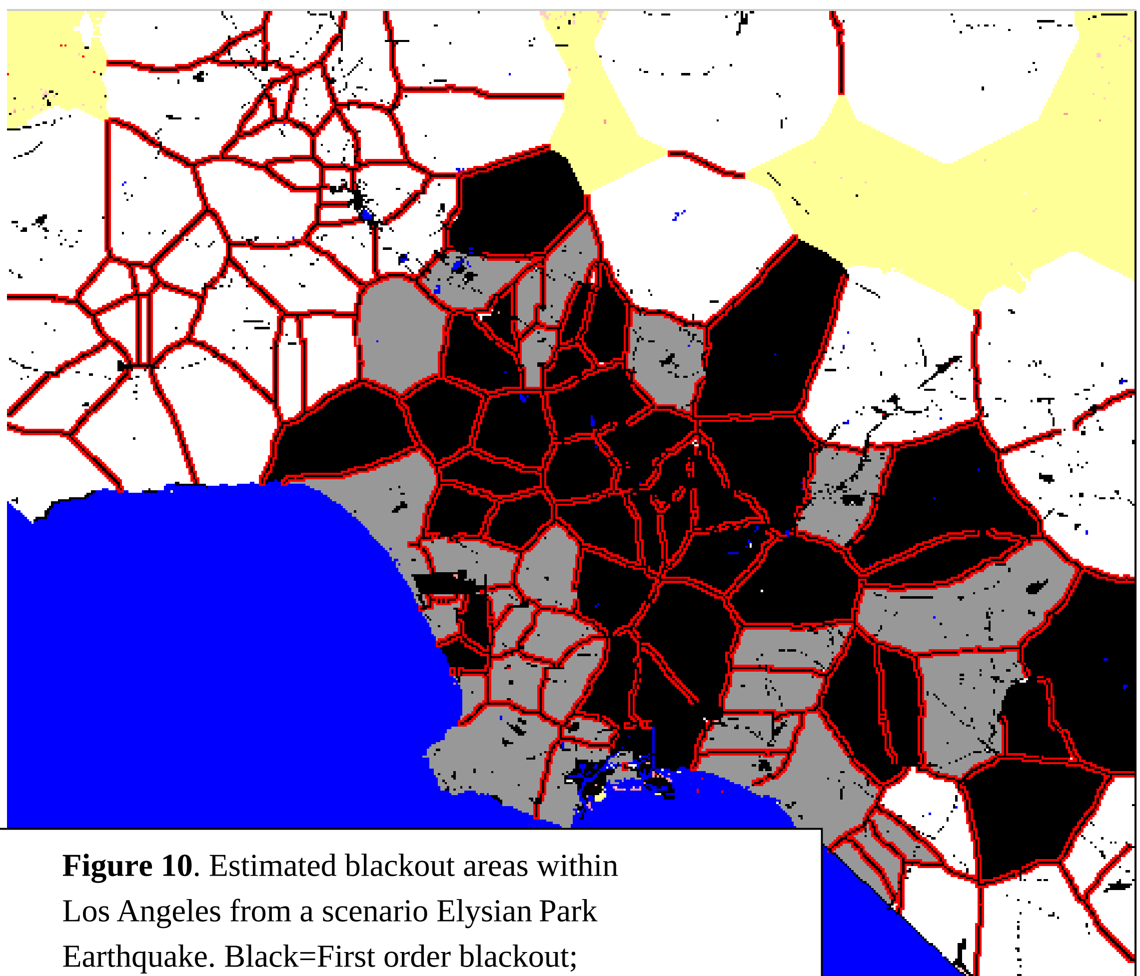

**Figure 10**. Estimated blackout areas within Los Angeles from a scenario Elysian Park Earthquake. Black=First order blackout; grey=second order blackout; red lines=substation service area boundaries.

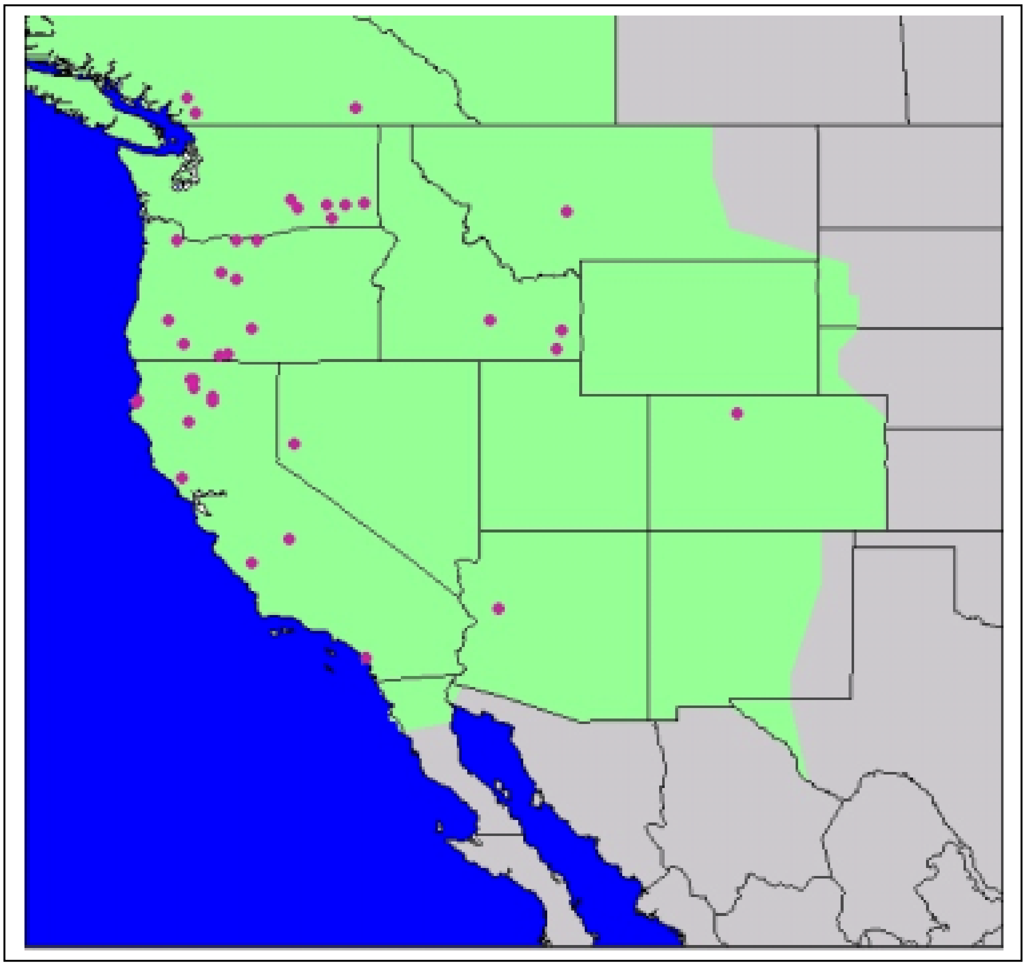

**Figure 11**. Locations of substations in the Western Systems Coordinating Council having abnormal voltages following a scenario Elysian Park earthquake in Los Angeles. Light shaded area is the region served by the WSCC member utilities.

**Professional Meetings and Workshops**

May 3-5, 1999. Seismological Society of America, 94th Annual Meeting (Olsen, Bradley).

September 7-9, 1999. Stress-Triggering Deformation Software Training Workshop. (Bradley, Jones, Olsen)

December 13-17, 1999. American Geophysical Union, Annual Fall Meeting (Olsen).

August 21-25, 1999. Urban and Regional Information Systems Association, Chicago (Maheshwari).

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## URBAN GROWTH DYNAMICS STUDIES

We have developed a Markov Random Field model that estimates the most suitable future land use for any given location. This model is a result of a collaboration with researchers at Memorial University and the UC Santa Barbara and is a generalization of two existing urban evolution models developed at these universities. In essence, the simulation “grows” new activities for a given location depending on what was there initially, the land use pattern in the neighborhood around the location, together with zoning, physical suitability, transportation access, and demographics and economic factors.

A "road-making" simulation is being developed that can eventually operate in concert with other subsystems of a city. This simulation will cover co-evolution of a city with its transportation infrastructure. This simulation can be used to compare the evolutionary model with the road system in an existing city or to anticipate roads that will grow along with a new city. If successful, the tool can be used for planning and to determine the cost structure and transportation efficiency.

## DECISION-MAKING

Disaster preparation involves multiple stakeholders and agencies and relies on predictive simulations. To facilitate this process, we are developing an Internet-based web environment that allows multiple organizations to solve collective problems. We have initiated a web-based emergency planning effort for earthquake preparedness in the Los Angeles area. Twenty different agencies have already signed up to participate. The disaster-preparedness web environment will contain three parts: (a) detailed scenario data from earthquake simulations together with damage estimates from different potential earthquakes; (b) information about the mission, mode of operation, etc, of each of the involved stakeholders and other information provided by the participating stake-holders; and (c) an interactive area where each stake-holder can sort disaster planning issues according to importance, order necessary actions in time sequence, request resources, etc. (Fig. 12)

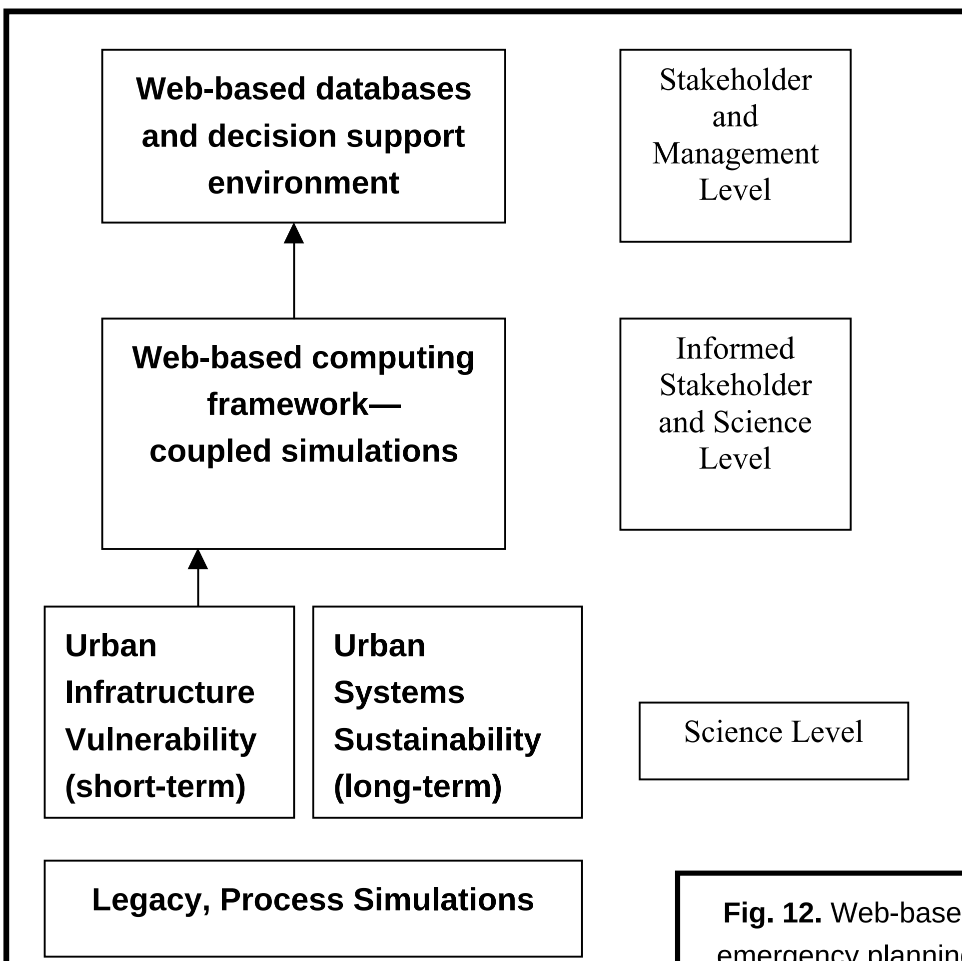


**Fig. 12.** Web-based emergency planning.

**Professional Meetings and Workshops**

- Chatanooga Conference on "Tools for Community Design and Decision-Making" (Rasmussen, Fogel).
- 24th Annual Hazards Research and Applications Workshop, Boulder, CO (Rasmussen was on the panel, "Decision support systems: New contributions from technology."
- FEMA (Federal Emergency Management Agency) Conference

# Framework

## L2F- Legacy to the Future

The purpose of the Legacy to the Future Framework is to provide an integrated modeling system of new and legacy code components that builds upon the strength in scientific modeling and simulation of Los Alamos National Laboratory. Existing modeling systems have been narrow in focus, and efforts to link existing codes have been tedious and uncommon. However, new advances in computational tools enable a more general solution to this problem.

**ACCOMPLISHMENTS DURING 1998-1999:**

Legacy to the Future is implemented using JAVA and CORBA. This combination allows communication among objects written in different languages across address spaces and networks. It allows for the incorporation of existing legacy codes while adhering the following seven design criteria: (1) Extensible, (2) Distributed, (3) Multi-user, (4) Parallel, (5) Secure, (6) User friendly, and (7) Easily implemented. There are many advantages of this design. Any code module, existing or newly developed, may be added to the system. Any user with network access may use the system, but modules may restrict access for security. Many users can use the system at the same time. Legacy codes can run on the most appropriate platform avoiding conversion costs and providing for parallel computation where appropriate. A minimum amount of work is required to add a module to the system.

Legacy to the Future consists of a setup server and its associated run-history database, application servers, clients, and optional authentication and security services. Adding an application to the framework requires writing its input specification using the framework grammar and implementing its application server according to the defined framework IDL (interface description language). The setup server and client remain unchanged. A client requests a run specification through the setup server causing a GUI to be automatically generated. The user may edit the specification, register a new specification, request a simulation to be run, visualize results, or select among other supported actions. We demonstrated a Legacy to the Future implementation of a related set of codes native to UNIX and PC platforms.

**Main Accomplishments:**

- The setup server supports any JDBC compliant database. We are currently using both ORACLE and ACCESS databases. (Fig. 13)

- Demonstrated L2F with setup and application servers on both UNIX (SGI and Solaris) and Windows (98 and NT) platforms. (Fig. 14)
- Added SWMM (storm water management model) application server
- Implemented synchronous and asynchronous servers:
- Asynchronous application servers allow display of intermediate results as the application runs. The client is released for other actions.
- Synchronous application servers are appropriate for applications with short run times. The client cannot proceed until the application is finished.
- Implemented visualization of input data (Fig. 15)
- Integrated HTTP file server to support file browsing.
- Implemented file browsing. From the client, the user can view an application's input and output files. The associated viewer is activated automatically.
- The first release of L2F has been cleared for open source distribution.

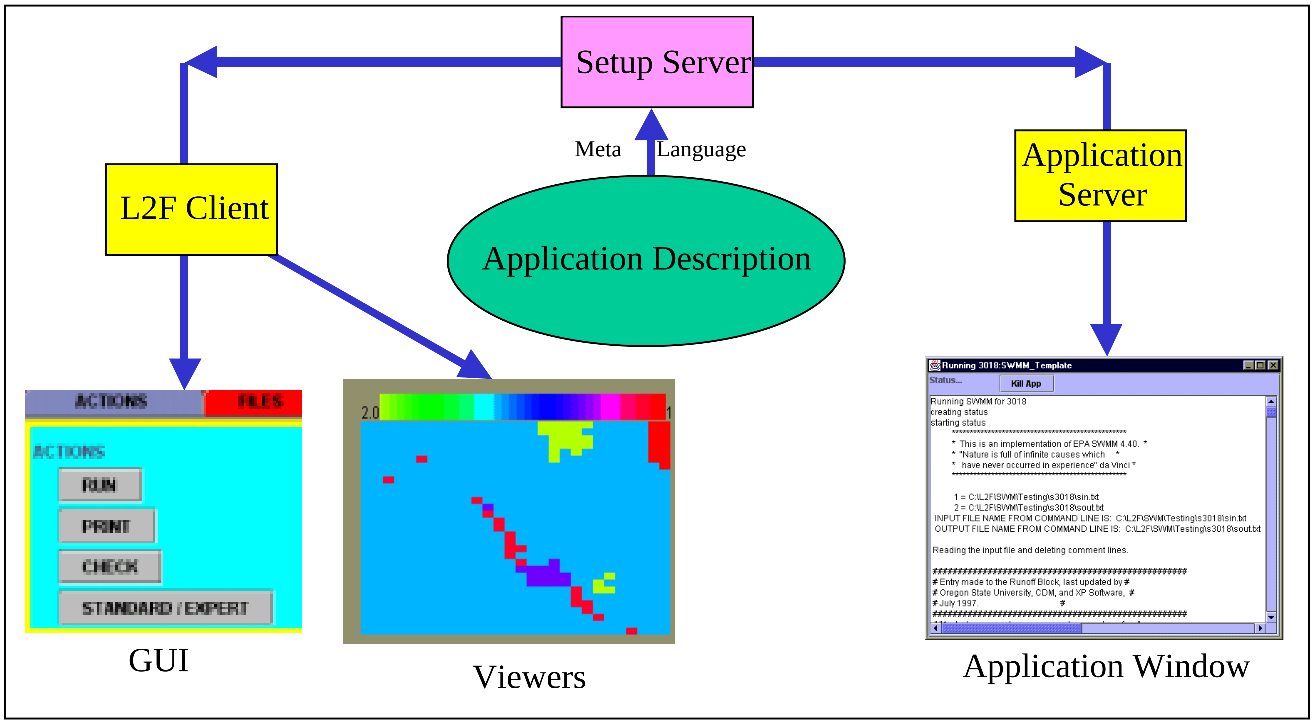


**Fig. 13.** Legacy to the Future (L2F) setup server.

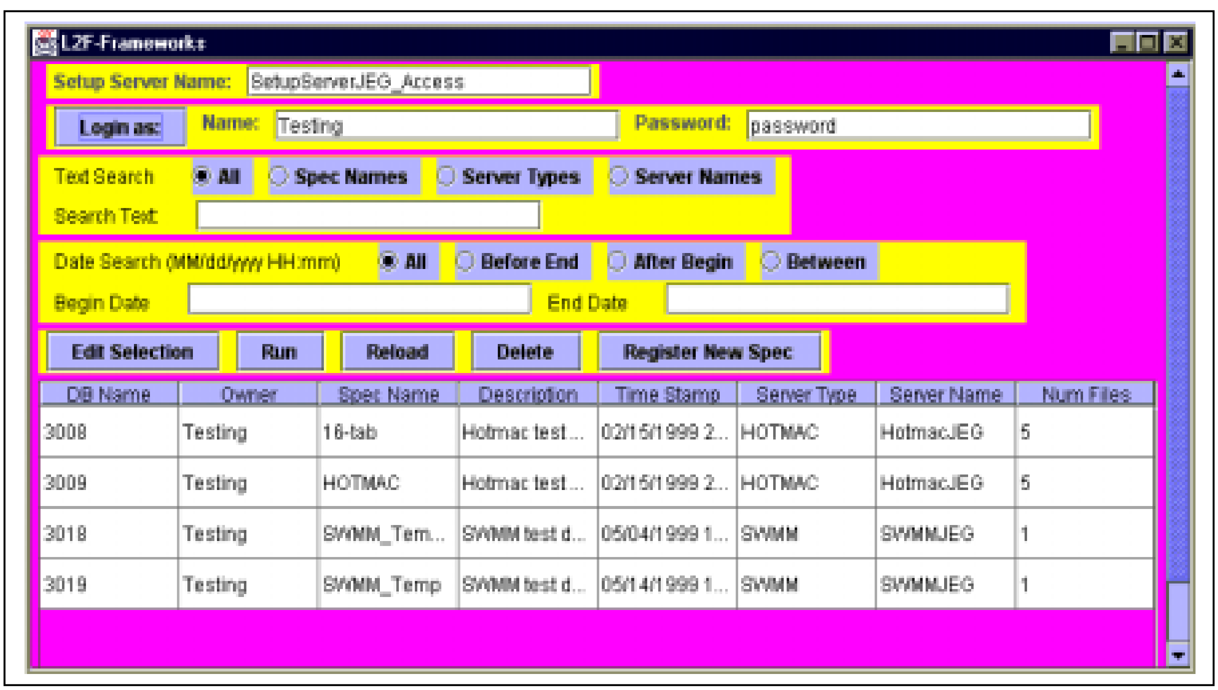


**Fig. 14.** L2F Setup and application server.

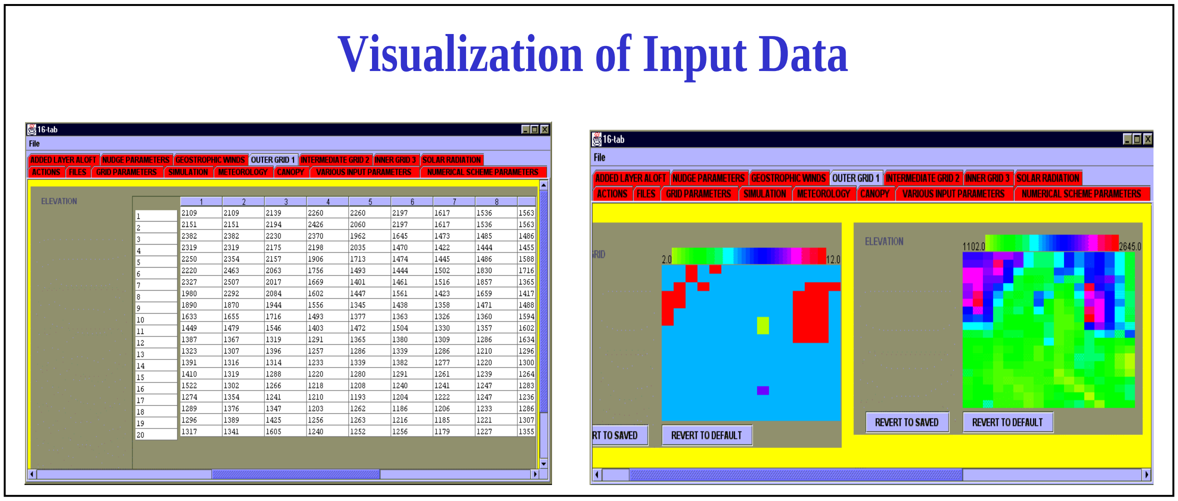


**Fig. 15.** L2F visualization of input data.

## OTHER ACCOMPLISHMENTS OF THE URBAN SECURITY TEAM

At the quadrennial meeting of the International Union of Geodesy and Geophysics (July, 1999, Birmingham, UK), two team members (Heiken and Valentine) were co-convenors of a special Union session on "Megacities and Geophysics." They are also on a Union committee to encourage geoscientists to re-direct many of their activites to urban problems. To encourage an outlet for these research activities, we are working toward making day-long sessions on urban geoscience a traditional part of the meetings of the Union and its 7 Associations. Heiken gave an invited talk on "Volcanoes and Megacities" at the same meeting.

To communicate the need for Urban Security tools for planning, vulnerability and sustainability analyses to the cities, the initiative has been described to potential end-users at a workshop in Los Angeles, at the annual meeting of the National League of Cities, and at the Pacific Rim Mayor's Conference.

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M. Brown, S.Burian, , T. McPherson, , G. Streit, , K. Costigan, and R. Greene, "Integrated air and water quality modeling system: application to the Los Angeles metropolitan area," submitted to the Second AMS Symposium on Environmental Applications, Long Beach, CA, (1999).

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T. McPherson, S. Burian, M. Brown, G. Streit, H. J. Turin, and K. Costigan, "Modeling the urban air and water environment," to be submitted to Urban Water Journal, (1999).

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**PROJECT PERSONNEL AT LOS ALAMOS**

*Chris Bradley,* EES-5. Ph. D. Seismology. Earthquakes and infrastructure, Southern California.

*Michael Brown:* TSA-4. Ph.D. Atmospheric Sciences. Areas of Interest: Turbulence, Boundary-layer, Plume Dispersion, Urban Canyon, and Mesoscale Meteorological Modeling.

*Keeley Costigan:* EES-5. PhD., Atmospheric Sciences. Areas of Interest: Numerical simulation with the Regional Atmospheric Modeling System (RAMS) and analysis of complex terrain meteorology, including flow in valleys and air quality studies. Numerical simulation of the large eddies of the atmospheric boundary layer and their interaction with larger scale circulation.

*L. Jonathan Dowell,* TSA-4, Engineering physics, applied mathematics, scientific computing, and power-systems analysis.

*Chuck Farrar,* ESA-Div. Ph. D. Structural Engineering; vibration-based damage identification. Seismic analyses of highway structures.

*Denise George:* T-1. MS, Computer Sciences. Areas of Interest: Software System Design, Parallel and Distributed Computing.

*Jim George,* ACL, Ph.D., Computer Science. Area of Interest: distributed object design.

*Robert Greene,* EES-5. GIS, Applied mathematics.

*Grant Heiken:* EES-1. Ph.D., Geology. Areas of Interest: Natural hazards, applied volcanology, urban geology.

*Eric Jones:* EES-5. Ph.D., Astronomy. Areas of Interest: Seismology, numerical modeling, space. Laboratory Fellow.

*Steen Rasmussen:* EES-5. Ph.D., Theoretical Physics. Areas of Interest: Simulation and dynamics of self-organizing processes.

*La Ron Smith:* TSA-DO/SA. PhD. Nuclear Engineering. Areas of Interest: complex systems, risk management, transportation simulation.

*Gerald Streit.* TSA-4. Air quality and chemical mechanism modeling.

*Jake Turin:* CST-7. Ph.D., Hydrology. Areas of Interest: Vadose-zone hydrology, subsurface contaminant transport, groundwater geochemistry, and karst hydrology.

*Greg Valentine:* EES-5. Ph.D., Geology. Areas of Interest: Transport processes in geologic media, plumes, convection, magma dynamics, flow in porous media, explosive volcanism, high-speed multi-phase flows, computational fluid dynamics, hydrothermal systems, planetary processes.

## Graduate Students

*Claes Andersson*—Department of Physics and Physical Resource Theory, Chalmers University of Technology, Sweden. Urban evolution dynamics, urban phase transitions, and urban regrowth after disasters (GRA).

*Steve Burian*, University of Alabama. Storm water modeling, civil engineering (GRA).

*Andy Lee*, UCLA, civil engineering, urban runoff modeling (GRA)

*Tim McPherson*, UCLA, environmental engineering, biology, (GRA).

*Sudha Mahashwari*, Rutgers University, urban planning and natural disasters (GRA).

*Aindrais O'Calloghan*—Computer Science, Princeton University. Technical and programming issues associated with the web based disaster planning and management environment (GRA).

## Collaborators

*Arizona Statue University Center for Environmental Studies*—Developing collaboration with the ASU team on Long-Term Environmental Research on Phoenix.

*Donald Duke*, UCLA—Environmental Science and Engineering, School of Public Health, chemistry of stormwater runoff

*Renato Funiciello*—Universita di Roma-III, Italy, Urban Geology Group.

*Jill Andrews*, Southern California Earthquake Center (University of Southern California)

*Kim Olsen*, UC-Santa Barbara—Institute of Crustal Studies

*Giovanni Orsi*—Osservatorio Vesuviano, Napoli, Italy, Volcanoes in Cities

*Spyros Pandis*, Carnegie Mellon, Air Chemistry.

*Ted Russell* – Georgia Inst. of Technology, Air Chemistry.

*Michael Stenstrom*— UC-Los Angeles, Civil and Environmental Engineering.

*Mel Suffet* – UC-Los Angeles, Environmental Engineering and Chemistry.

*Wing Tam*, LA County Storm Water Bureau, storm water runoff in Los Angeles

*Roger White*—Memorial University, St. Johns, Newfoundland, Modeling City Growth

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